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Causes And Consequential Costs Of Anthropogenic Climate Change

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ABSTRACT

On the one hand, this paper examines the costs directly caused by climate change, also comparing the possible costs for preventing damage; on the other hand, it compares the effects of the radiation propulsion caused by anthropogenic greenhouse gas emissions on anthropogenic heat generation through the use of all types of fuels. In addition to the global warming effect caused by anthropogenic heat radiation, there are also local heat islands that are affected by a much greater rise in temperature.

Purpose: A cost comparison of the damage caused by climate change and a quantitative comparison of the direct heat development through the use of fuels with the radiative forcing through anthropogenic greenhouse gas emissions.

Design / methodology / approach: In both cases, the research method is based on the analysis of public databases such as the International Energy Agency (IAE), as well as published literature on global energy supply and the Federal Statistical Office.

Results: The expected consequential damage caused by climate change will probably present most states with insoluble financial burdens. The radiation propulsion from anthropogenic greenhouse gas emissions makes an 80 times greater contribution to global warming than the anthropogenic heat generation from all types of fuels.

Research / practical implications: Future research should show the consequences for the economy and the acquisition of money on the one hand and on the other hand include the effects of global warming and the heat islands, both of which lead to a loss of habitat.

Originality / Value: This paper has both the expected follow-up costs in view as well as the causes and effects of anthropogenic greenhouse gas emissions.

Keywords: Costs of climate damage, consequences of climate change due to the radiation forcing.

INTRODUCTION

Anthropogenic climate change (and its reasons) causes costs from a business perspective for companies and from an economic perspective for the state and thus for taxpayers. It is interesting to note that there are currently very few studies on the costs that are directly related to this. One of the reasons for this may be that it is difficult to assess which costs are directly related and which are only indirect. Sir Nicholas Stern (Stern, 2006) suspects that economic effects in this regard could amount to up to 20% of GNP / GDP in 2100. It is also difficult to assess which costs could only come from Germany, since illnesses and changes in mortality (OECD, 2004) can only be incorporated into causal chains to a limited extent. Claudia Kemfert (Kemfert, 2007) calculated for climate damage, adaptation measures and other costs of € 800 billion for 50 years. These are ex-post considerations.

Whether the costs for greenhouse gas reductions as an ex-ante approach are much lower as claimed can (Edenhofer, et al, 2010), with the associated conditions such as close cooperation in technological innovations and cross-border emissions trading, be limited to a total of 1% of global economic output will be, although this total would certainly be very significant. Nevertheless, one should assume that prevention (ex-ante) is cheaper than cure (ex-post), if that is still possible (Kemfert, 2005).

It is also problematic to calculate costs that cannot be charged directly to a company, its insurance company or the state. Victims of heat, natural disasters such as cyclones and floods, which are often no longer insurable due to the high probability of occurrence, or the simple non-growth of plants, due to drought and / or elevated temperatures, as well as future increasing flows of refugees (new term "climate refugees"), here not included (Globalisierung). However, the costs for this arise.

Max Aurel (Aurel, 2016) writes that 10-12% of economic output should be seen as a loss if the temperature rises by 4 ° C. The possible consequences will be very different, which also results in the problem of the calculation. Changed crop yields on land and at sea are difficult to bill for. It becomes even more difficult when changing tourism flows or when (non-) buying products due to climate change. So-called “tipping points”, which will trigger selfreinforcing damage, are particularly problematic. Even external effects or externalities are not measured here, so that there will be losers (e.g. insolvent companies), which are not counted under climate change costs, but in any case belong to them. The consequences will also become clear in the insurance sector. Even if you ignore the usual fluctuations in the year, it is financially very difficult if the costs of environmental damage at a local insurance company in Germany increase practically by 100% from 2015 to 2016. According to calculations by the German Institute for Economic Affairs, individual German federal states alone will face cumulative losses of € 100 billion (DIW, 2008).

PROBLEMS BETWEEN CLIMATE PROTECTION COSTS AND CLIMATE DAMAGE

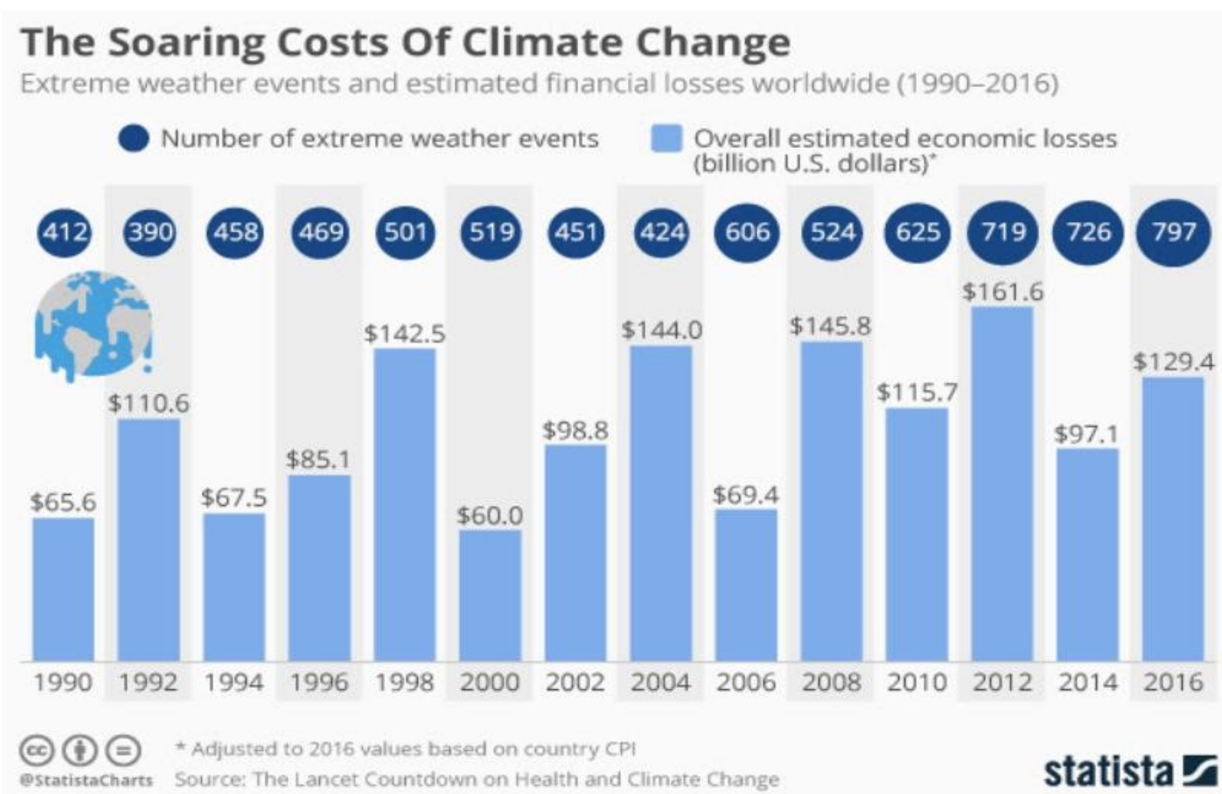
Of particular interest here is a comparison of climate protection costs (ex-ante) compared to climate damage that has already occurred (ex-post). Depending on whether the measures were started in 2005 or will not start until 2025, the costs of the damage increase exponentially. Here, too, it becomes clear that preventive measures are not only more sensible, but also simply cheaper than those that are repaired afterwards (Venjakob, et al, 2013).

At the start of climate protection	Results in the year	Climate protection costs and damage in bill €
2005	2050	400
		1.400
	2100	3.000
		3.400
2025	2050	500
		3.900
	2100	3.400
		15.400

Own illustration based on Venjakob et al. The values only refer to Germany and are discounted to the year 2002.

Whether the scenario of the International Energy Agency (IEA) of 450ppm CO_2 is feasible or what happens if it is exceeded (possibly even significantly) should not even be discussed here. According to its own calculations, the OECD assumes costs of around 5.5% of global GDP. However, these are only the direct negative effects associated with the rise in temperature. A counter-calculation with possible positive effects is not carried out, since these are probably still much more difficult to assess.

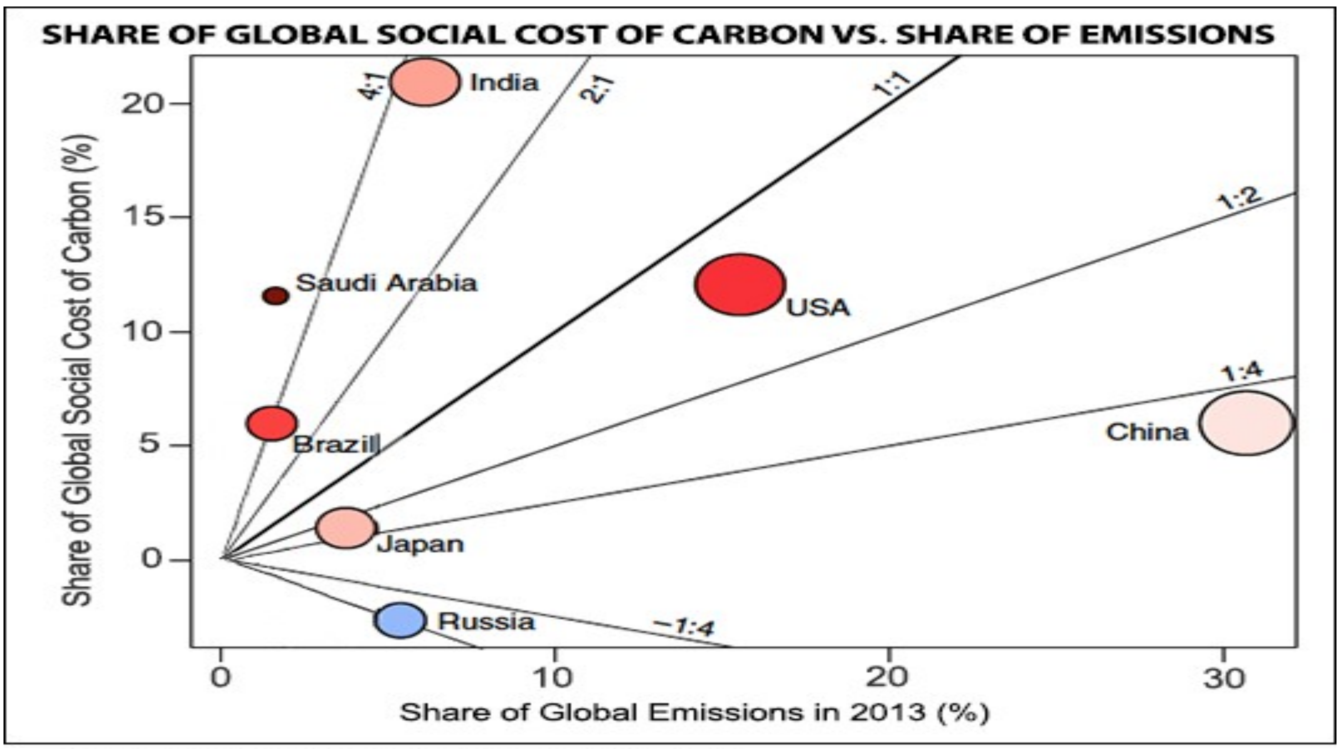
Dyfed Loesche (Loesche, 2017) also focuses on the costs and the number of events because these are probably easier to measure. The following graphic illustrates the trend towards both a larger number of extreme weather events and larger losses due to these. Adjusted for price, the net increase was around 53% in 10 years (own calculation by the autor).



The numbers in the oval blue circles above show the number of extreme weather events, the columns show the estimated losses in USD billion, both values per year and worldwide.

Stacy Morford's (Morford, 2018) long contribution refers to various scientists, both Kate Ricke from the University of San Diego and the legendary paper by Dietz / Stern. According to Ken Caldera, calculations at the Carnegie Institute of Science showed costs of USD 417 / ton worldwide. By today's standards, a sum of direct and indirect costs or damage that can no longer be represented by the global economy. If these authors even suspect this sum to be an undervaluation because numerous developments in their model are not even taken into account, it becomes clear which financial challenges also face global mankind.

Incidentally, the fact that the environmental damage is very likely to be distributed discontinuously and the costs it will incur is another injustice that will affect the individual states. If one takes into account in this regard that states usually do not pay external damage in other states (only to a limited extent as an exception in the European Union via emergency aid funds), then it becomes clear that there is also among the states from the perspective of financial climate consequences, winners and will give losers, with all the associated consequences.



Source: Ricke, et al., Nature Climate Change, 2018

We come to the conclusion of the first part: According to different calculation models, several hundred billion euros per country or up to 20% of GDP as damage to the environment of the countries of the world. Different scientists from the USA and Europe calculated this independently of each other, so that's probably the way it is. The costs for prevention (ex-ante) are probably much lower than if one had to remedy the resulting climate damage (ex-post). There are numerous climate impacts that cannot (or cannot) be measured, even if they are based directly or indirectly, e.g. changed or disappeared vegetation, changed tourist flows and millions of climate refugees. As of 2020, it is not even possible to begin to assess whether target values such as a temperature rise of 2 ° C or 450 ppm CO2 will be reached. In any case, however, the climate impact costs, currently an average of a good 50% in 10 years, already adjusted for inflation. Final costs of up to over USD 400 / tonne of CO2 emitted worldwide (without the inflation to be added) illustrate the urgency of acting NOW. The fact that the resulting damage / costs do not arise 1: 1 for those who caused it may only appear as another example of worldwide injustice.

Avenue of future research:

- Which direct costs can be realistically assumed for climate damage by 2030/2050 and which indirect costs?
- Are there mathematical models that can be used to determine an index value that measures climate change costs on the one hand and temperature increases / influences on the other? If not, what should it look like?
- Which anthropogenic factors affecting temperature increase, apart from CO2, should be given much more attention in the future due to their influence?
- Have any indexes been developed that measure the difficulty in reducing anthropogenic temperature increases?

INFLUENCE OF MANMADE ACTIVITIES

After the costs, a look should now be taken at the actual causes why temperatures are really rising. The repeated prayer-wheel-like claim in the media that it would only be due to CO2 is as one-sided as it is false. Neutral calculations on this are very rare and were therefore carried out here. Due to their diversity, no claim to final validity is raised.

Since the beginning of the industrial age in 1750, the concentration of greenhouse gases such as carbon dioxide, methane, nitrous oxides and halocarbons increased significantly. In the pre-industrial age the atmospheric concentration of carbon dioxide concentration levelled in the range of 275-284 ppm (Etheridge, 1996). Actual values from Mauna Loa Observatory for 2019 show 411 ppm (NOAA, 2020).

Atmospheric greenhouse gas concentrations in the stratosphere cause a radiative forcing which is essential for the global temperature conditions. Without this radiative forcing, global mean temperature would be -18 °C. By the pre-industrial level of atmospheric carbon dioxide concentration (and other greenhouse gases), the global mean temperature has been approx. (14,8 °C (Ramanathan et al, 1989).

In (Ramaswamy et al, 2001) the effect of increasing greenhouse gas concentrations to the radiative forcing is given by

$$\Delta F = 5{,}35 \cdot \ln(C_{CO}2{,}actual / C_{CO}2{,}reference)\ \mathrm{W/m^2}$$

Since the greenhouse effect of different greenhouse gases varies, respective formulas are given for methane, nitrous oxide, etc. The total effect on radiative forcing is given by summing up each greenhouse gas contribution.

In IPCC's *CLIMATE CHANGE 2013, The Physical Science Basis* (Stocker, 2014) the additional radiative forcing, introduced by anthropogenic greenhouse gas emissions in the period 1750-2011 is given by

$$\Delta F = 2{,}3\ \mathrm{W/m^2}$$

This additional term amounts marginal in contrast to the solar constant, which is specified by the International Astronomical Union (IAU) to E_0 = 1.061 W/m². The absolute value of the extraterrestrial irradiance varies during a year in the range of 3,3…+3,4 % due to the orbit's eccentricity. The atmospheric transmissivity reduces the solar irradiance to approx. 1.000 W/m² on ground level at clear skies and noon time.

It is important to note that the later value is a maximum value, which is observed during daytime and varies widely by actual weather conditions as well as solar altitude. During night time the solar irradiance is zero. In consequence the two values of irradiance and radiative forcing cannot be compared although they look similar. In order to understand the consequence of the additional radiative forcing from anthropogenic greenhouse gas emissions, the heat equivalent of the radiative forcing is compared to other anthropogenic heat sources such as global combustion of fossil fuels and nuclear heat generation.

METHODOLOGY

The equivalent heat of radiative forcing by anthropogenic greenhouse gas emissions is calculated by

$$Q_r = p_r \cdot A_E \cdot t$$

With p_r: specific radiant power; 2,3 W/m², A_E: surface of earth; 510 million km², t: time of a year; 8.760 h/a

$$Q_r = 10{,}23 \cdot 10^{15}\ \mathrm{kWh/a}$$

Thermal energy developed from fossil and nuclear fuels is estimated by the global production of the fuels and their specific calorific values, respectively. From this gross sum non-energetic use and energy conversion (electricity generation and transport) is deducted. For transport an average efficiency of 25 % is estimated to calculate residual heat. Figures for fuel production and fuel use are derived from (Int. Energy Agency, 2020) for 2017.

Finally the (residual) heat from fossil and nuclear fuels is summed up and compared to the equivalent energy of radiative forcing. Further transformation processes and losses need not be evaluated. Conversion losses in energy systems and industrial processes are transferred into heat. Additional effects by intake to/outtake from bunkering are minor in effect and therefore neglected.

CALCULATION

Table 1. Global production of fuels

Coal	Q_c = 3.773.421 ktoe/a = 43,9 · 10^{12} kWh/a
Crude oil	Q_o = 4.477.212 ktoe/a = 52,1 · 10^{12} kWh/a
Natural gas	Q_g = 3.162.893 ktoe/a = 36,8 · 10^{12} kWh/a
Nuclear fuels	Q_n = 687.481 ktoe/a = 8,0 · 10^{12} kWh/a
Biomass, waste	Q_b = 1.324.112 ktoe/a = 15,4 · 10^{12} kWh/a
Total heat	Q_{fuels} = 159,2 · 10^{12} kWh/a

All data from (Int. Energy Agency, 2020).

In addition, geothermal heat for power production and heat use totals to Q_t = 0,3 · 10^{12} kWh/a. Due to the low value, the technical use of geothermal heat is not further part of the consideration. The total heat is a gross value, which need to be deducted by

- Conversion of heat into mechanical energy (power stations, motors)
- Non-energetic use for material use

Table 2. Power production

Coal	$E_{c,p}$ = 9.863.339 GWh/a = 9,9 · 10^{12} kWh/a
Crude oil	$E_{o,p}$ = 841.878 GWh/a = 0,8 · 10^{12} kWh/a
Natural gas	$E_{g,p}$ = 5.882.825 GWh/a = 5,9 · 10^{12} kWh/a
Nuclear fuels	$E_{n,p}$ = 2.636.030 GWh/a = 2,6 · 10^{12} kWh/a
Biomass, waste	$E_{b,p}$ = 595.572 GWh/a = 0,6 · 10^{12} kWh/a
Total electricity	E_{elec} = 19,8 · 10^{12} kWh/a

In respect to total global power production, fuel-based units provide still more than three quarters (77,1 %) of all electricity generation. Despite global additions of renewable power producers, hydro power contributes by further 16 % – a larger share than all other renewables in total.

Since all type of electric devices and appliances provide for a finite efficiency, shares of electricity production are transferred back to heat. Conventional lightning equipment provides for poor efficiency. In particular heat devices like ovens or heaters in households and industries, cooling devices, and finally the supply system itself by transmission losses in lines, cables and transformers produce heat. Thus, the here presented value for conversion of heat into electricity in terms of less heat production is likely to be over-estimated, because a significant share of electricity is transferred back to heat.

Table 3. Mobility

Crude oil	$E_{o,m}$ = 2.494.307 ktoe/a · 25 % = 7,3 · 10^{12} kWh/a
Natural gas	$E_{g,m}$ = 4.871.316 TJ/a · 25 % = 0,3 · 10^{12} kWh/a
Biomass, waste	$E_{b,m}$ = 83.589 ktoe/a · 25 % = 0,2 · 10^{12} kWh/a
Total mechanical energy	E_{mech} = 7,8 · 10^{12} kWh/a

The efficiency of motors varies widely by type of construction and mode of application. Best point efficiency will be rarely reached in common mobility scenarios, while particular examples such as transport by sea look more favorable. Nevertheless, the total amount of heat, which is converted into momentum, is comparatively less to total fuel production.

Table 4. Non-energetic use

Coal	$E_{c,n}$ = 50.570 ktoe/a = 0,6 · 10^{12} kWh/a
Crude oil	$E_{o,n}$ = 231.952 ktoe/a = 2,7 · 10^{12} kWh/a
Natural gas	$E_{g,n}$ = 8.650.853 TJ/a = 2,4 · 10^{12} kWh/a
Total non-energetic	E_{none} = 5,7 · 10^{12} kWh/a

Table 6: Total non-heat use

Total electricity	E_{elec} = 19,8 · 10^{12} kWh/a
Total mechanical	E_{mech} = 7,8 · 10^{12} kWh/a
Total non-energetic	E_{none} = 5,7 · 10^{12} kWh/a
Total non-heat energy	E_{nonh} = 33,3 · 10^{12} kWh/a

Estimation of the non-heat use of fuels allows a first overview on the effective heat emissions (not: exhaust gases) to the ambient and finally into the atmosphere. To obtain the effective heat emissions, the total calorific value of fossil and nuclear fuels produced is reduced by the energy demand for non-heat use. Since total figures for non-heat use are small compared to the total heat production, the effect on heat emission deduction is of less relevance for the final result.

Anthropogenic heat production from fuels

Total anthropogenic heat production is given by total heat production deducted by non-heat use of fuels such as electricity production, mechanical energy for mobility or machinery use and non-energetic use as calculated above.

$$Qheat,anth = Qfuels - Enonh$$

$$Q_{heat,anth} = 159{,}2 \cdot 10^{12} \text{ kWh/a} - 33{,}3 \cdot 10^{12} \text{ kWh/a} = 125{,}9 \cdot 10^{12} \text{ kWh/a}$$

COMPARISON AND CONCLUSION

The additional radiative forcing, which is introduced by anthropogenic greenhouse gas emissions, has been calculated to

$$Qrad.force = 10{,}23 \cdot 1015 \text{ kWh/a}$$

Compared to the above value, the total anthropogenic heat production contributes just to a minor extent to global warming

$$Qheat,anth = 125{,}9 \cdot 1012 \text{ kWh/a}$$

$$Q_{h}eat,anth/Q_{rad}.force = 1{,}22\ \%$$

Although the additional radiative forcing by anthropogenic greenhouse gas emissions provides for a comparatively small value of 2,3 W/m^2, the contribution to global warming is more than 80-times higher than the heat production from all fuels and all processes globally. This result emphasizes on the importance of greenhouse gas abatement. The effect of present and future greenhouse gas intake by the atmosphere is many times higher than any man-made heat production. Further global warming will have a strong effect on energy demand, since the need for cooling and air condition will increase – and due to finite efficiency of cooling devices, further net heat intake to environment and atmosphere will occur.

ADDENDUM: URBAN HEAT ISLANDS

Beyond the global approach applied above, there are local urban heat islands which result from the physical properties of urban environments and from anthropogenic heat emissions. The concentration of both, buildings and population, is much higher than in rural areas. The anthropogenic heat emissions result from heating the buildings and the use of appliances (in particular for cooling) and vehicles driven by combustion engines (Forster, 2007).

In 1998 Nakićenović published a global total value for the specific heat flux from urban agglomerations of approx. 0,03 W/m². During the past decades, both, the global population and the physical urbanization have dynamically increased, particularly in Asia and Africa. While global population reached 6,06 billion in 1999, for 2020 7,79 billion have been estimated by the UN (UN, 2020). For this reasons the heat flux value given above must be regarded as a bottom most estimate for the actual situation. Putting the focus on urban areas, only, significantly higher values of specific heat flux appear. In 2000 a mean local heat flux in a city has been calculated to 65 W/m² (Loveland et al, 2000). At that time (1999) in central Tokyo daytime values in excess of 400 W/m² are observed. Top most values during winter reach 1.590 W/m² (Ichinose, 1999).

Although anthropogenic heat production in total is small compared to the heat flux from radiative forcing caused by accumulated anthropogenic greenhouse gas emissions, there is an significant impact to local climate conditions (Crutzen, 2004), (Betts, 2004). The Deutscher Wetterdienst (DWD, German Weather Service) states that in particular during summer periods with high pressure weather, air temperature may amount up to 10 °C higher inside the urban area in contrast to the urban hinterland (Deutscher Wetterdienst, 2020).The United States Environmental Protection Agency (EPA) presents a temperature difference between cities of more than one million inhabitants and their nearby rural areas of 1…3 °C, which may reach up to 12 °C in the evening hours (US Environmental Protection Agency, 2020).

Multiple effects contribute to this temperature increase, such as anthropogenic heat emissions, heat storage effects, or heat reflection and absorption of solar irradiation. Additionally, ambient temperature level is affected by climate change. Further research by IPCC and others should find be performed:

- To identify contributors and their contribution to heat islands, as well as measures to reduce the different effects
- To provide numerical models, which may support city planners to identify hot spots in urban areas and develop countermeasures.

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